REPORT NO. FRA-ORD&D-75-2

INTRODUCTION TO THE APPLICATION OF THE DYNALIST COMPUTER PROGRAM TO THE ANALYSIS OF RAIL SYSTEMS DYNAMICS

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AUGUST 1974

INTERIM REPORT

DOCUMENT IS AVAILABLE TO THE PUBLIC
THROUGH THE NATIONAL TECHNICAL
INFORMATION SERVICE, SPRINGFIELD,
VIRGINIA 22151.

Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Research, Development, and Demonstrations
Washington DC 20590

02-Track-Train Dynamics

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Technical Report Documentation Page

1. Report No. FRA-ORD&D-75-2	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle INTRODUCTION TO THE APPLICATION OF THE DYNALIST COMPUTER PROGRAM TO THE ANALYSIS OF RAIL SYSTEMS DYNAMICS		5. Report Date August 1974 6. Performing Organization Code
7. Author(s) A.B. Perlman, J.J. Lanza		8. Performing Organization Report No. DOT-TSC-FRA-74-2
9. Performing Organization Name and Address U.S. Department of Transportation Transportation Systems Center Kendall Square Cambridge MA 02142		10. Work Unit No. (TRAIS) RR-415/R4309 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Railroad Administration Office of Research, Develop. and Demonstr. Washington DC 20590		13. Type of Report and Period Covered Interim Report January-March, 1974 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

DYNALIST, a computer program that extracts complex eigenvalues and eigenvectors for dynamic systems described in terms of matrix equations of motion, has been acquired and made operational at TSC. In this report, simple dynamic systems are used to define the DYNALIST terminology. Input parameters required to model a rail vehicle are described. Preparation of a card deck to run the program is detailed. The program output is examined in terms of an application to a hunting analysis of a rail vehicle.

17. Key Words Rail Vehicle Dynamics	18. Distribution Statement DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22151.

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 46	22. Price

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

PREFACE

In support of the Federal Railroad Administration, the Transportation Systems Center under RR415 is identifying, collecting, and extending analytical techniques and computer programs for prediction of rail systems dynamic performance. As part of this effort, the DYNALIST computer program has been acquired and made operational at TSC. The program extracts complex eigenvalues and and eigenvectors for damped dynamic systems which can be described in terms of matrix equations of motion.

The work described here is an introduction to the application and use of the program for hunting analyses of rail vehicles. The lateral dynamic stability analysis provides a prediction of vehicle speed ranges in which large oscillations of the vehicle body or components may occur. These oscillations contribute to passenger discomfort and wheel and rail wear at low speeds and become violent at high speeds, leading to severe flange impact or possible derailment.

This document is intended to be an interim guide to the computer program. It will be superseded by a final report by J.H. Wiggins. Co., Inc. on their contract with TSC to extend DYNALIST to provide a capability for a prediction of rail system response to track inputs.

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1. INTRODUCTION

DYNALIST is a computer program which calculates eigenvalues and eigenvectors for dynamic systems which can be described in terms of matrix equations of motion of the form

$$[M] \left\{\ddot{X}\right\} + [C] \left\{\dot{X}\right\} + [K] \left\{X\right\} = 0$$

This complex eigen-extraction of damped systems permits application of the program to a lateral dynamic stability or hunting analysis of rail vehicles. The analytical technique used in the program is component mode synthesis.

This report is intended as an interim guide to users of the program as implemented by TSC on a CDC 6600 computer at CDC Waltham. DYNALIST is presently being extended by J.H. Wiggins under contract to TSC to provide response capabiltiy. It is expected that the final report for that contract will supersede this document for application to rail systems.

Detailed descriptions of the component mode method and a listing of DYNALIST may be found in References 1, 2, and 3. Further details of the program such as flow diagrams are contained in a manual prepared for WYLE Laboratories by J.H. Wiggins.[4]

In this report, a simple example dynamic system is used to define some of the terminology of component mode synthesis used in DYNALIST. The form of the input parameters required to describe a rail vehicle model for DYNALIST is outlined. Preparation of a card deck for a rail vehicle model is described in detail. Finally, DYNALIST output is discussed in terms of its application to a hunting analysis for a rail vehicle.

2. DEFINITIONS AND COMMENTS

The component mode formulation on which DYNALIST is based permits analysis of complex dynamic systems by coupling of several simpler systems. The user describes the system in terms of equations of motion of the subsystems and relations which connect the subsystems. In addition, several coordinate transformations are performed in the program which require certain inputs.

Some component mode concepts and definitions as implemented in DYNALIST are illustrated in the simple system of Figure 1. This system is considered by coupling the two subsystems of Figures 2a and 2b.

The matrix equations of motion for component 1 are:

$$\begin{bmatrix} m_2 & 0 \\ 0 & 0 \end{bmatrix} \begin{Bmatrix} \ddot{y}_1 \\ \ddot{y}_2 \end{Bmatrix} + \begin{bmatrix} c_2 & -c_2 \\ -c_2 & c_2 \end{bmatrix} \begin{Bmatrix} \dot{y}_1 \\ \dot{y}_2 \end{Bmatrix} + \begin{bmatrix} k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix} \begin{Bmatrix} y_1 \\ y_2 \end{Bmatrix} = 0$$

y_2 is defined as a *constraint coordinate* which will be connected to component 2. It may be viewed as an "extra" coordinate, added for this purpose.

y_1 is defined as a *free coordinate*.

For component 2, the matrix equations of motion are:

$$[m_1] \left\{\ddot{X}_1\right\} + [0] \left\{\dot{X}_1\right\} + [0] \left\{X_1\right\} = [0]$$

X_1 is defined as a *rigid body coordinate*.

DYNALIST requires a transformation of coordinates, $[\Phi]$, that orders the coordinates of any subsystem as: constraint; rigid body; free. Therefore $[\Phi]$ is composed of identity and null submatrices.

For component 1, $[\Phi_1] = \begin{bmatrix} 0 & I \\ I & 0 \end{bmatrix}$

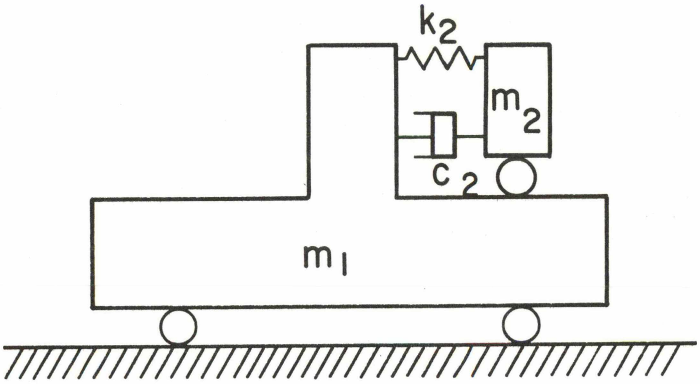

Figure 1. Assembled System

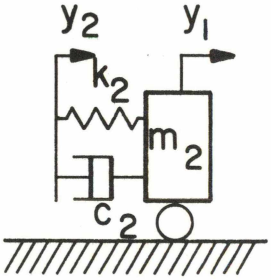

Figure 2a. Component 1

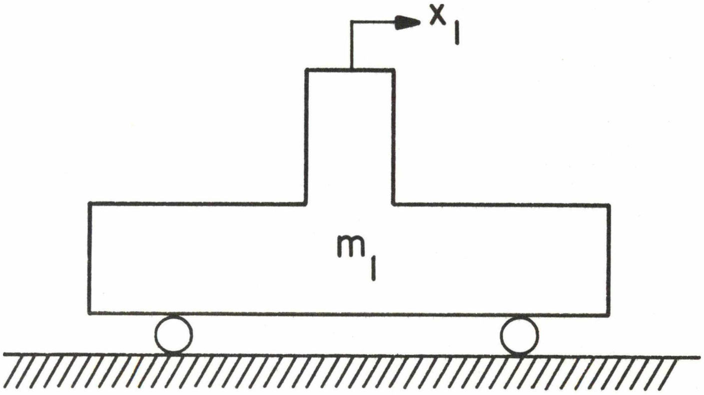

Figure 2b. Component 2

For component 2, $[\Phi_2] = [I]$

In this simple case, the submatrices are just one element since there is only one coordinate of a given type in each component.

The assembled system is a "sum" of component 1 and component 2 with a coordinate description

$$\{q\} = \begin{Bmatrix} y_1 \\ y_2 \\ X_1 \end{Bmatrix} = \begin{Bmatrix} q_1 \\ q_2 \\ q_3 \end{Bmatrix}$$

subject to the constraint,

$X_1 = y_2$, or, $y_2 - X_1 = 0$.

Constraints on an assembled system are described in DYNALIST by an (n x m) G matrix. n is the number of constraint equations. m is the total number of system coordinates, i.e., a set of matrix equations, $[G]\{q\} = 0$. In this case,

$$[G] = [0 \quad 1 \quad -1]$$

a 1 x 3 matrix.

DYNALIST also requires the coordinates of the final system to be arranged so that all of the dependent coordinates (those in the constraint relations) are first, followed by the independent coordinates. This reordering (IARANG in DYNALIST instructions) is performed on the coordinate order after the individual Φ transformations.

In this example,

$$\{q\}_1 = \begin{Bmatrix} y_1 \\ y_2 \\ X_1 \end{Bmatrix} = \begin{Bmatrix} q_1 \\ q_2 \\ q_3 \end{Bmatrix} \qquad \text{original order}$$

$$\{q\}_2 = \begin{Bmatrix} y_2 \\ y_1 \\ X_1 \end{Bmatrix} = \begin{Bmatrix} q_2 \\ q_1 \\ q_3 \end{Bmatrix} \qquad \text{after } \Phi \text{ transformations}$$

$$\{q\}_3 = \begin{Bmatrix} y_2 \\ X_1 \\ y_1 \end{Bmatrix} = \begin{Bmatrix} q_2 \\ q_3 \\ q_1 \end{Bmatrix}$$ dependent, y_2 and x_1, then independent, y_1

IARANG relates the order of $\{q\}_2$ to the order of $\{q\}_3$ by $\begin{Bmatrix} 1 \\ 3 \\ 2 \end{Bmatrix}$. q_2 first, q_1 third, and q_3 second in $\{q\}_3$.

A further advantage of the component mode method is illustrated by the system in Figure 3 which can be considered as an assembly of the same subsystems of Figures 2a and 2b. This assembly is component 1 plus component 2 plus another component 1.

$$\{q\} = \begin{Bmatrix} y_1 \\ y_2 \\ X_1 \\ y_1 \\ y_2 \end{Bmatrix} = \begin{Bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \\ q_5 \end{Bmatrix}$$

$$[G] = \begin{bmatrix} 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 & -1 \end{bmatrix}$$

The same ϕ_1 order applies to component 1 for q_1, q_2 and q_4, q_5, so that IARANG relates

$$\begin{Bmatrix} q_2 \\ q_1 \\ q_3 \\ q_5 \\ q_4 \end{Bmatrix} \text{ to } \begin{Bmatrix} q_2 \\ q_3 \\ q_5 \\ q_1 \\ q_4 \end{Bmatrix}$$

by

$$\begin{Bmatrix} 1 \\ 4 \\ 2 \\ 3 \\ 5 \end{Bmatrix}$$

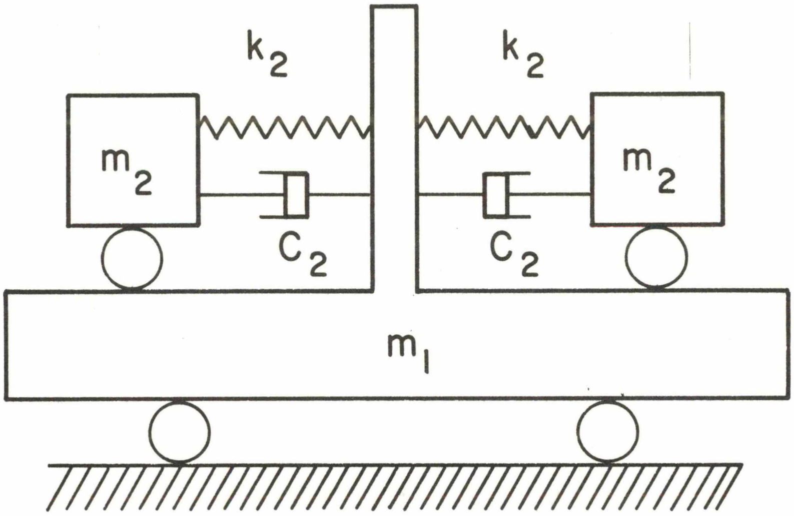

Figure 3. Assembled System

3. RAIL VEHICLE ASSEMBLY - INPUT PARAMETERS

Application of DYNALIST to a rail vehicle is a test example described in References 1 and 3. This section discusses the input and output of that example in terms of the definitions of Section 2.

The rail vehicle in Figure 4 is a 14 degree of freedom lateral dynamics model. It is assembled using two eight degree of freedom trucks and a two degree of freedom body (Figure 5).

The truck has six free coordinates and two, u_7 and u_8, constrained coordinates. The parameters of Table 1 are input in terms of the mass, damping and stiffness matrixes of Tables 2, 3, and 4. The (8 x 8) Φ matrix, of Table 5, is of the form,

$$[\Phi] = \begin{bmatrix} 0 & I_1 \\ I_2 & 0 \end{bmatrix}$$

where I_1 is (6 x 6) and I_2 is (2 x 2).

Corresponding inputs for the two degree of freedom, rigid body model of the vehicle body are indicated in Table 6.

Assembly of the complete vehicle is prescribed by the G matrix and IARANG vector indicated by Table 7.

Note that these tables are not the forms of input that go into the program. They are rather the information needed for the input. The line by line instructions for card deck preparation to run DYNALIST are detailed in Section 4.

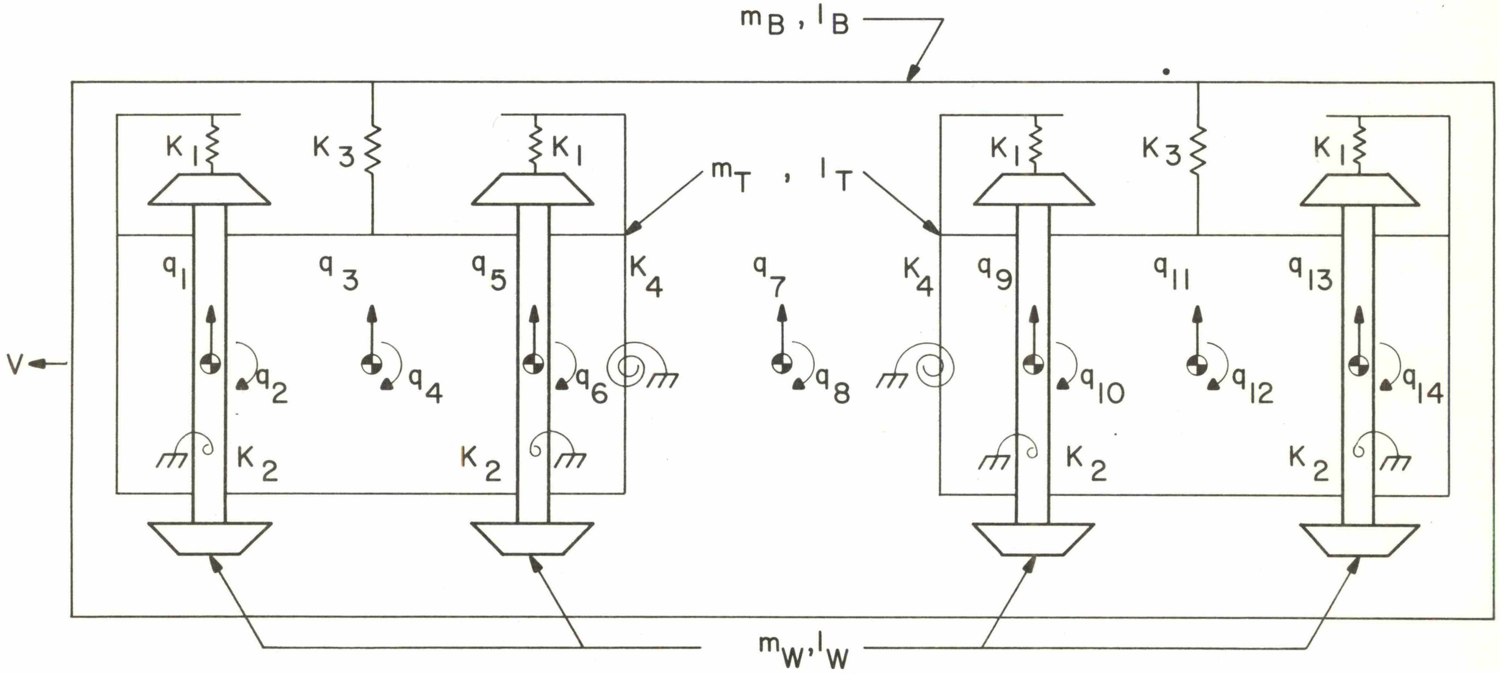

Figure 4. 14 Degree of Freedom Vehicle

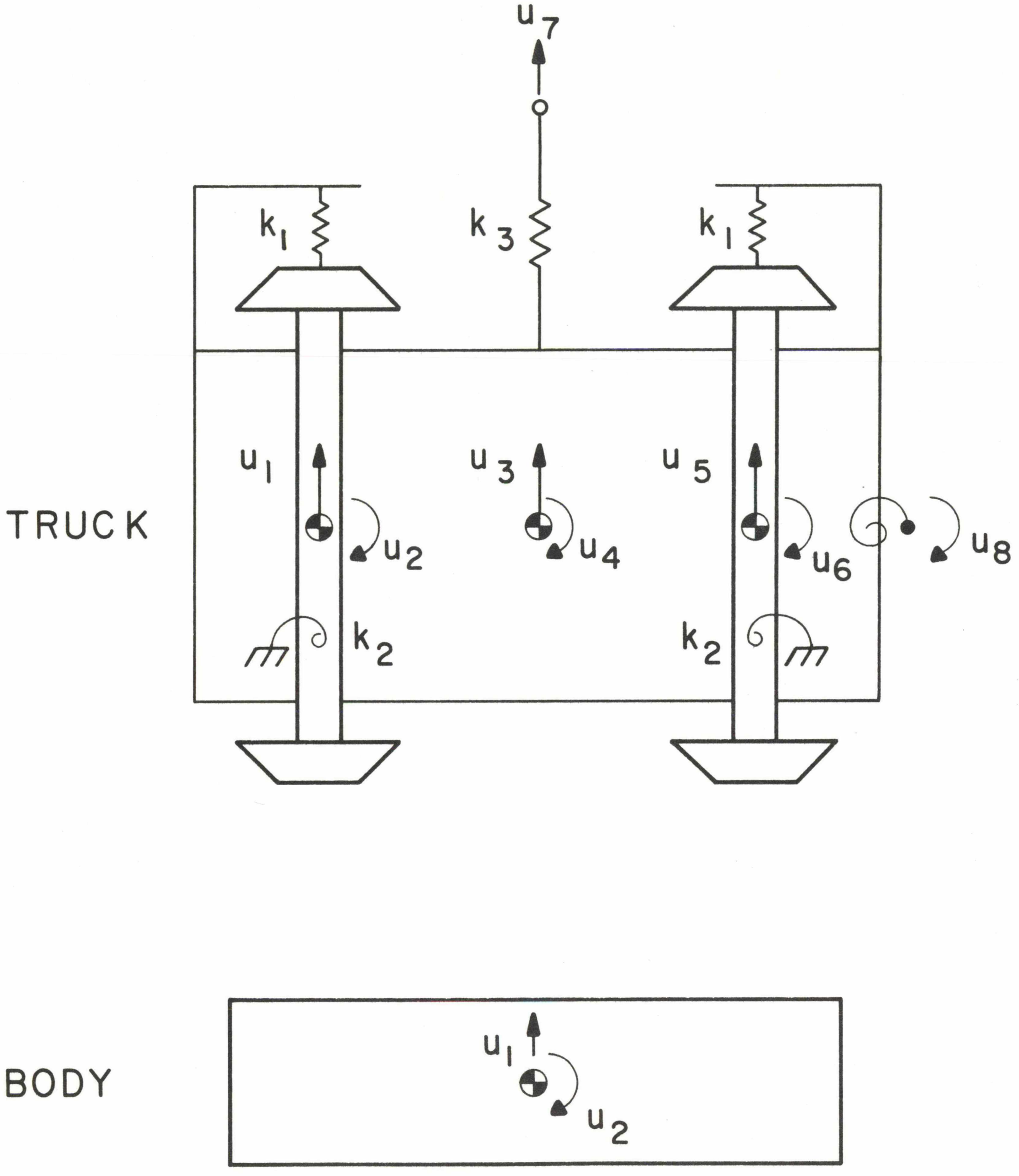

Figure 5. Truck and Car Body Components

TABLE 1. PARAMETER VALUES FOR 14 D.O.F. TVS CAR[1]

Description	Symbol	Value
Mass Properties		
Wheelset Mass	m_W	60 slugs
Wheelset Moment of Inertia	I_W	290 slug-ft^2
Truck Mass	m_T	250 slugs
Truck Moment of Inertia	I_T	2800 slug-ft^2
Car Body Mass	m_B	1700 slugs
Car Body Moment of Inertia	I_B	1.85×10^6 slug-ft^2
Primary Suspension		
Lateral Damping	C_1	0 lb sec/ft
Lateral Stiffness	K_1	5×10^5 lb/ft
Yaw Damping	C_2	0 ft lb sec/rad
Yaw Stiffness	K_2	3×10^7 ft lb/rad
Secondary Suspension		
Lateral Damping	C_3	1.55×10^3 lb sec/ft
Lateral Stiffness	K_3	1.75×10^4 lb/ft
Yaw Damping	C_4	0 ft lb sec/rad
Yaw Stiffness	K_4	5×10^6 ft lb/rad
Other Parameters		
Half-Distance Between Truck Centerlines		41.5 ft
Half Track Gage		2.5 ft
Truck Wheelbase		8 ft
Mean Wheel Cone Angle		.025 rad
Wheel Radius		1.33 ft
Creep Coefficient		3×10^6 lbs
Velocity		450 ft/sec

TABLE 2. TRUCK MASS MATRIX

```
 THE FOLLOWING INFORMATION IS FOR COMPONENT   1.00


THE TOTAL NUMBER OF COORDINATES (NJ) =     8
THE NUMBER OF CONSTRAINED COORDINATES (NCON ) =    2


THE NUMBER OF RIGID BODY COORDINATES (NRIGS)=    0

THE NUMBER OF FREE COORDINATES (NFREE)=    6

THE MASS MATRIX (AMASS) LISTED BY ROWS.


ROW    1
 6.00000E+01 0.          0.          0.          0.          0.          0.          0.

ROW    2
 0.          2.90000E+02 0.          0.          0.          0.          0.          0.

ROW    3
 0.          0.          2.50000E+02 0.          0.          0.          0.          0.

ROW    4
 0.          0.          0.          2.80000E+03 0.          0.          0.          0.

ROW    5
 0.          0.          0.          0.          6.00000E+01 0.          0.          0.

ROW    6
 0.          0.          0.          0.          0.          2.90000E+02 0.          0.

ROW    7
 0.          0.          0.          0.          0.          0.          0.          0.

ROW    8
 0.          0.          0.          0.          0.          0.          0.          0.
```

TABLE 3. TRUCK DAMPING MATRIX

```
THE DAMPING MATRIX (DAMP) LISTED BY ROWS.

ROW   1
 1.33000E+04 0.          0.          0.          0.          0.          0.          0.

ROW   2
 0.          8.33000E+04 0.          0.          0.          0.          0.          0.

ROW   3
 0.          0.          1.55000E+03 0.          0.          0.         -1.55000E+03 0.

ROW   4
 0.          0.          0.          0.          0.          0.          0.          0.

ROW   5
 0.          0.          0.          0.          1.33000E+04 0.          0.          0.

ROW   6
 0.          0.          0.          0.          0.          8.33000E+04 0.          0.

ROW   7
 0.          0.         -1.55000E+03 0.          0.          0.          1.55000E+03 0.

ROW   8
 0.          0.          0.          0.          0.          0.          0.          0.
```

TABLE 4. TRUCK STIFFNESS MATRIX

```
THE STIFFNESS MATRIX (STIFF) LISTED BY ROWS.

ROW   1
 5.00000E+05-6.00000E+06-5.00000E+05-2.00000E+06 0.          0.          0.          0.

ROW   2
 2.82000E+05 3.00000E+07 0.         -3.00000E+07 0.          0.          0.          0.

ROW   3
-5.00000E+05 0.          1.01750E+06 0.         -5.00000E+05 0.         -1.75000E+04 0.

ROW   4
-2.00000E+06-3.00000E+07 0.          8.10000E+07 2.00000E+06-3.00000E+07 0.         -5.00000E+06

ROW   5
 0.          0.         -5.00000E+05 2.00000E+06 5.00000E+05-6.00000E+06 0.          0.

ROW   6
 0.          0.          0.         -3.00000E+07 2.82000E+05 3.00000E+07 0.          0.

ROW   7
 0.          0.         -1.75000E+04 0.          0.          0.          1.75000E+04 0.

ROW   8
 0.          0.          0.         -5.00000E+06 0.          0.          0.          5.00000E+06
```

TABLE 5. TRUCK Φ MATRIX

```
THE MATRIX RELATING THE RIGID BODY, CONSTRAINED, AND FREE COORDINATES
TO THE ORIGINAL COMPONENT COORDINATES (MATRIX PHI).

ROW    1
 0.           0.           1.00000E+00 0.           0.           0.           0.           0.

ROW    2
 0.           0.           0.           1.00000E+00 0.           0.           0.           0.

ROW    3
 0.           0.           0.           0.           1.00000E+00 0.           0.           0.

ROW    4
 0.           0.           0.           0.           0.           1.00000E+00 0.           0.

ROW    5
 0.           0.           0.           0.           0.           0.           1.00000E+00 0.

ROW    6
 0.           0.           0.           0.           0.           0.           0.           1.00000E+00

ROW    7
 1.00000E+00 0.           0.           0.           0.           0.           0.           0.

ROW    8
 0.           1.00000E+00 0.           0.           0.           0.           0.           0.

THE FREE COORDINATES ARE.

   1     2     3     4     5     6
```

TABLE 6. [M], [C], [K], and $[\Phi]$ FOR VEHICLE BODY

```
 THE FOLLOWING INFORMATION IS FOR COMPONENT   2.00


THE TOTAL NUMBER OF COORDINATES (NJ) =      2
THE NUMBER OF CONSTRAINED COORDINATES (NCON ) =     0


THE NUMBER OF RIGID BODY COORDINATES (NRIGS)=    2

THE NUMBER OF FREE COORDINATES (NFREE)=    0

THE MASS MATRIX (AMASS) LISTED BY ROWS.


ROW   1
 1.70000E+03 0.

ROW   2
 0.          1.85000E+06

THE DAMPING MATRIX (DAMP) LISTED BY ROWS.


ROW   1
 0.          0.

ROW   2
 0.          0.

THE STIFFNESS MATRIX (STIFF) LISTED BY ROWS.


ROW   1
 0.          0.

ROW   2
 0.          0.

THE MATRIX RELATING THE RIGID BODY, CONSTRAINED, AND FREE COORDINATES
TO THE ORIGINAL COMPONENT COORDINATES (MATRIX PHI).


ROW   1
 1.00000E+00 0.

ROW   2
 0.          1.00000E+00

THE FREE COORDINATES ARE.

    0
```

TABLE 7. [G] AND IARANG

```
THE MATRIX OF CONSTRAINTS (MATRIX G).


COLUMN    1
 0.          0.          0.          0.

COLUMN    2
 0.          0.          0.          0.

COLUMN    3
 0.          0.          0.          0.

COLUMN    4
 0.          0.          0.          0.

COLUMN    5
 0.          0.          0.          0.

COLUMN    6
 0.          0.          0.          0.

COLUMN    7
 1.00000E+00 0.          0.          0.

COLUMN    8
 0.          1.00000E+00 0.          0.

COLUMN    9
-1.00000E+00 0.         -1.00000E+00 0.

COLUMN   10
-4.15000E+01-1.00000E+00 4.15000E+01-1.00000E+00

COLUMN   11
 0.          0.          0.          0.

COLUMN   12
 0.          0.          0.          0.

COLUMN   13
 0.          0.          0.          0.

COLUMN   14
 0.          0.          0.          0.

COLUMN   15
 0.          0.          0.          0.

COLUMN   16
 0.          0.          0.          0.

COLUMN   17
 0.          0.          1.00000E+00 0.

COLUMN   18
 0.          0.          0.          1.00000E+00

THE COORDINATES ARE TO BE REARRANGED TO THE FOLLOWING ORDER.

     1     2     7     8     9    10    11    12     5     6     3     4
    13    14    15    16    17    18
```

4. PREPARATION OF AN INPUT DECK

Table 8 is a listing of the cards required to run DYNALIST for an analysis of the vehicle model of Figure 6. The assembly is similar to the example in section 3. It consists of the assembly of two axles and a body shown in Figure 7.

This section explains, line by line, the control cards for the program as compiled on the CDC 6600 at CDC Waltham and the namelist input format to DYNALIST. See reference 4 for further descriptions of the program flow and usage.

4.1 USAGE

The program consists of three segments.

Segment 1:

Determines eigenvectors and eigenvalues (modes) for a component (such as single axle or a car body) and creates a component data file.

Segment 2:

Edits (removes modes from) a component data file.

Segment 3:

Combines the edited modes (i.e. assemble a rail vehicle by combining 2 axle assemblies and a car body) and determines the final modes (eigenvectors and eigenvalues).

To determine the final modes of a whole rail vehicle, the user always begins the execution of the program at segment 1. This creates separate data files for each component, i.e. if a rail vehicle consists of two axle assemblies and a body assembly both the axle assembly data and the body data are solved in segment 1.

4.2 INPUT PARAMETERS AND FORMAT

Before examining the DYNALIST input format, explicit instructions are given on control cards for the use of CDC 6600 computer

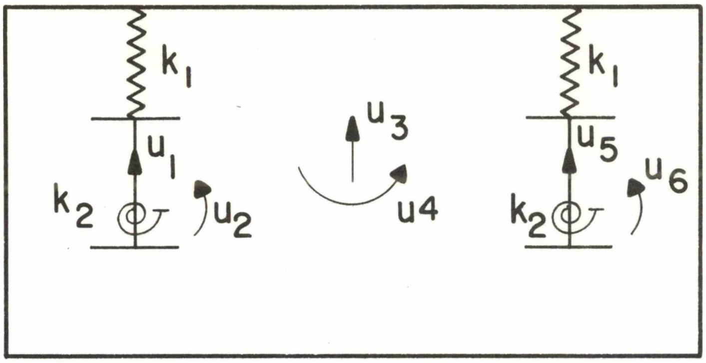

Figure 6. 2-Axled Vehicle

Figure 7. Components of 2-Axled Vehicle

TABLE 8. PROGRAM INPUT

```
$SEQUENCE,CAS.
$CHARGE,S7901R3-001.
JOB,CM250000,T300,P6.
ATTACH(LGO,CASB)
SET(0)
LOAD(LGO)
NOGO.
TEMP.
0000000000000000000000
      TWO TRUCK AND SINGLE BODY VEHICLE TEST *** RUN BY J.J. LANZA
 $START NTYPE=1,NEWTAP=0,
 $END
 $COMPO
 COMNAM=1.00,NJ=4,
 IFOUT=0,
 NCON=2,NRIGS=0,
 ISYMC=1,ISYMK=1,
 AMASS(1,1)=60,AMASS(2,2)=290,
 DAMP(1,1)=1.33E4,DAMP(2,2)=8.33E4,
 STIFF(1,1)=5E5,2.82E5,-5E5,
 STIFF(1,2)=-6E6,3E7,0,-3E7,
 STIFF(1,3)=-5E5,0,5E5,
 STIFF(1,4)=0,-3E7,0,3E7,
 NFREE=2,NCORCN(1)=1,2,
 PHI(1,3)=1,PHI(2,4)=1,PHI(3,1)=1,PHI(4,2)=1,
 $END
 $START NTYPE=1,NEWTAP=1,
 $END
 $COMPO
 COMNAM=2.00,NJ=2,
 IFOUT=0,
 NCON=0,NRIGS=2,
 NFREE=0,
 AMASS(1,1)=250,AMASS(2,2)=2800,
 PHI(1,1)=1,PHI(2,2)=1,
 $END
 $START NTYPE=2,
 $END
 $EDITT
 NMODE2(1)=4,0,
 MODES(1,1)=1,2,3,4,
 $END
 $START NTYPE=3,
 $END
 $SYN
 IFOUT=0,NCOMP=3,NROWG=4,
 PRENAM(1)=1.00,2.00,1.00,
 G(1,3)=1,G(2,4)=1,G(3,9)=1,G(4,10)=1,
 G(1,5)=-1,0,-1,
 G(1,6)=-4,-1,4,-1,
 IARANG(1)=1,2,7,8,5,6,3,4,9,10,
 $END
 $START NTYPE=4,$END
0000000000000000000000
```

(since the inexperienced user most often makes mistakes in this area). NOTE: Use 026 punch only.

Card 1 (Starting in column 1):

$SEQUENCE,XXX.

XXX are three leters or numbers used for billing purposes by CDC to the user's company.

Card 2 (Starting in column 1):

$CHARGE,YYYYYYY-VVV.

The number after the comma is the user's CDC charge account number.

Card 3 (Starting in column 1):

JOB,CM250000,T300,P2.

CM250000 saves 250K units (in octal) of central memory space for the user's program, T300 allots a maximum of 300 seconds for the run, and P2 assigns a low priority ("run overnight no hurry") to the program to keep the cost down. Note, although a "P6" priority will usually have a turnaround time of only 5 minutes to 2 hours, its cost is much greater than that of a P2 priority.

Card 4 (Starting in column 1):

ATTACH(LGO,CASB)

Card 5 (Starting in column 1):

SET(0)

Card 6 (Column 1):

LOAD(LGO)

Card 7 (Column 1):

NOGO.

Card 8 (Column 1):

TEMP.

Card 9 (Column 1):

7/8/9 (i.e. punch the numbers 7,8,9 in column 1 of the card. The reader interprets a 7/8/9 as a string of zeros: 0 0 0 0 0 ...).

The next step is to examine the DYNALIST input. Every card now starts in column 2 and column 1 is left blank.

Card 10 (Starting in column 2):

Title card. An appropriate title is given to the run.

Note also that the following cards are for a typical 2 axle single body assembled vehicle.

Card 11:

$START NTYPE=1, NEWTAP=0

NTYPE specifies the segment of the program to be run. NTYPE=1 indicates that the following data is for segment 1 of the program, (i.e. it determines the modes of the component).

Similarly

If NTYPE=2 segment 2 is called.

If NTYPE=3 segment 3 is called.

NEWTAP has to be specified only when NTYPE=1, and is ignored for NTYPE=2 or NTYPE=3. If a component is being analysed for the first time then NEWTAP=0 (i.e. a new component data file is created). If the data for the component which is to be analysed is to be added to an existing component data file then NEWTAP≠0. However, this option is rarely used.

Card 12 (Column 2):

$END

Card 13 (Column 2):

$COMPO

COMPO is used to create a new data file.

Card 14:

COMNAM=1.00, NJ=X,

According to the Wiggins user's manual COMNAM is a six digit "name" (F6.2) to be associated with the component data. However, in practice, the program seems to run only if COMNAM is a floating point number.

NJ denotes the number of degrees of freedom of the component. NJ is of the same order as the input mass, damping and stiffness matrixes (AMASS, DAMP & STIFF).

Card 15:

IFOUT=0,

IFOUT is a flag for printing results of intermediate calculations. If IFOUT=0 only the input and final results (eigenvalues and eigenvectors) will be printed. If IFOUT≠0 the results of most intermediate calculations will also be printed.

Card 16:

NCON=X, NRIGS=Y

NCON is the total number of constraint coordinates of the component.

NRIGS is the total number of rigid body coordinates of the component.

Card 17:

ISYMC=a, ISYMK=a,

If the component damping matrix (DAMP) is symmetric ISYMC may be set equal to zero and only the non-zero terms of the upper triangle of DAMP input. Otherwise all non-zero terms (ISYMC≠0) in the damping matrix must be input.

If the component stiffness matrix (STIFF) is a symmetric matrix ISYMK may be set equal to zero and only the non-zero terms of the upper triangle of STIFF input.

Cards 18.1 - 18.N: Mass matrix cards

AMASS(I,J)=(some value)., MASS(I,K)=etc, AMASS is the component's mass matrix. AMASS is of the same order a NJ. Only the non-zero terms need be entered.

Cards 19.1 - 19.N: Damping matrix cards

DAMP(I,J)=(some value), DAMP(I,K)=etc.,

DAMP is the component damping matrix. DAMP is of the same order as NJ. All non-zero terms are entered if ISYMC≠0. Only the non-zero terms of the upper triangle need be entered if ISYMC=0 in which case DAMP is assumed symmetric.

Cards 20.1 - 20.N: Stiffness matrix cards

STIFF(I,J)-(some value), STIFF(I,K)=etc.,

STIFF is the stiffness matrix components. STIFF is of the same order as NJ. All non-zero terms are entered if ISYMK≠0. Only the non-zero terms of the upper triangle need be entered if ISYMK=0, in which case STIFF is assumed symmetric.

Next, the procedure employed in punching a typical stiffness matrix on the input cards is described:

It is assumed that the stiffness matrix [K] for component 1.00 is as follows:

$$[K] = \begin{bmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \\ 9 & 10 & 11 & 12 \\ 13 & 14 & 15 & 16 \end{bmatrix}$$

STIFF(1,1) is column 1 of the matrix and is placed on the data card as follows, starting in column 2:

STIFF(1,1)=1,5,9,13

Similarly, column 2,3, and 4 of the matrix are input as follows:

STIFF(1,2)=2,6,10,14,

STIFF(1,3)=3,7,11,15

STIFF(1,4)=4,8,12,16

Now another stiffness matrix is examined. This time there will be some zeros in it that may or may not have to be entered. For example:

$$[K] = \begin{bmatrix} 1E3 & 0 & 0 & 9E4 \\ 0 & 0 & 2E3 & 0 \\ 5E4 & 0 & 0 & 0 \\ 0 & 6E3 & 5E6 & 0 \end{bmatrix}$$

Column one is entered as:

STIFF(1,1)=1E3,0,5E4,

The zero is entered to maintain the correct position of the 5E4 piece but the final zero is not punched on the card since it is assumed zero by the computer program.

The next column is represented as:

STIFF(4,2)=6E3,

That means that column two consists of one non-zero element in position 4. The three preceding zeros need not be entered.

The next column is input as follows:

STIFF(2,3)=2E3,0,5E6,

The first zero is ignored.

The final column is input as:

STIFF(1,4)=9E4,

The three trailing zeros are not input.

Card 21 (Starting in column 2):

NFREE=X, NCORCN(1)=a,b,c,

NFREE is the total number of free coordinates of the component.

NCORCN is a vector of length NFREE. NCORCN contains those coordinates (the free coordinates) which are to be used in determining the component modes. All coordinates not contained in

NCORCN are deleted from the mass, stiffness and damping matrices before the component modes are determined.

NCORCN(1) is the vector for component 1.00.

Cards 22.1 - 22.N: PHI matrix cards

PHI(I,J)=(some value), PHI(I,K)=etc.,

PHI is a matrix relating the component constraint, rigid body, and free coordinates to the component spatial coordinates (the coordinates used in constructing the mass, damping and stiffness matrices). PHI is an NJ by NCON+NRIGS+NFREE matrix. Only the non-zero terms of PHI need be entered.

Card 23 (Starting in column 2):

$END

This END card terminates the data for component 1.00.

Card 24:

$START NTYPE=1, NEWTAP=1

This calls segment one of the program again and NEWTAP=1 since the data for this new component is to be added to the existing component data file.

Card 25:

$END

Card 26:

$COMPO

Card 27:

COMNAM=2.00, NJ=X,

This tells the program that the following data is for component 2.00 (the body of the rail vehicle).

NJ was explained previously.

Card 28:

IFOUT=0,

Card 29:

NCON=a, NRIGS=y,

Card 30:

NFREE=X,

Cards 31.1 - 31.N: Mass matrix cards

AMASS(I,J)=(some value), AMASS(I,K)=some value,etc.,

This was explained previously.

Cards 32.1 - 32.N: PHI matrix cards

PHI(I,J)=(some value), PHI(I,K)=etc.,

This was explained previously.

Note both the stiffness and damping matrixes are zero in this case and thus are not input.

Card 33:

$END

Card 34:

$START NTYPE=2,

This calls segment 2 of the program which removes (EDIT) modes from a component data file.

Card 35:

$END

Card 36:

$EDITT

This calls namelist block EDITT.

Card 37 (Starting in column 2):

NMODE2(1)=X,Y,

NMODE2 is a vector which *must* contain a value for each component in the component data file. The value of NMODE2 signifies the number of modes to be retained on the edited component data tape for that particular component.

The first element of NMODE2 corresponds to the first component on the component data file, the second element corresponds to the second component, etc. The elements of MNODE2 must be less than or equal to the number of modes on the input component data file for the corresponding component. If no modes for a particular component are to be retained or the component had no normal modes to begin with, a zero must be entered for the corresponding element of NMODE2.

Card 38:

MODES(1,1)=a,b,c,d,

MODES is a matrix which specifies the modes to be retained for each component on the edited component mode data file. MODES (1,1) through MODES (NMODE(1),1) are the modes to be retained for the first component on the data file. MODES (1,2) through MODES (NMODES(2),2) are the modes to be retained for the second component on the data file, etc. The values of MODES (1,I) through MODES (NMODE2(I),I) must be greater than or equal to one and less than or equal to the number of modes recorded for component I on the input component data file.

Card 39:

$END

Card 40:

$START NTYPE=3,

This calls segment three of the program which synthesizes the edited component data file and determines the final modes.

Card 41:

$END

Card 42:

$SYN

This calls namelist block SYN.

Card 43:

IFOUT=0, NCOMP=a, NROWG=b,

NCOMP is the number of components involved in the synthesis. Note that if the data for a component on the component data file is used more than once, NCOMP is increment each time it is used.

NROWG is the number of rows of the constraint matrix (G).

Card 44:

PRENAM(1)=1.00,2.00,1.00,

PRENAM is a vector of length NCOMP. The values of PRENAM are floating point numbers of the format F6.2. The values of PRENAM correspond to the names given to the desired components on the input component data file.

Cards 45.1 - 45.N: G matrix cards

G(I,J)=(some value), G(I,K)=etc.,

G is the matrix defining the constraint relationships among the component coordinates. G has NROWG rows and a column for each unconnected coordinate for the complete system. NROWG is the number of constraint relationships.

The values of G(a,b) are input columnwise. The procedure is similar to inputting STIFF(a,b). For example:

$$[G] = \begin{bmatrix} 0 & 0 & 1 & 0 & -1 & -4 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 4 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 1 \end{bmatrix}$$

The first input card is

G(1,3)=1, G(2,4)=1, G(3,9)=1, G(4,10)=1,

All columns consisting of zeros are neglected and the columns with single non-zero values are input. (So columns 1,2,3,4,6,7,8, & 9 are taken care of by this one card).

The next input card is:

G(1,5)=-1,0,-1

which inputs the values of column six.

The program assumes a "zero" value for any matrix position not indicated on the data cards.

Card 46:

IARANG Card

IARANG is a vector used to rearrange the uncoupled coordinate so that the "dependent" coordinates appear first, followed by the "independent" coordinates.

For example, a 2 axle single body is examined. The first step is to list the coordinates and indicate the dependent coordinates.

$$\left[\begin{array}{c}1\\2\\3\\4\\5\\6\\7\\8\\9\\10\end{array}\right]\quad\begin{array}{l}\\ \\ \text{Dependent Coordinates}\\ \\ \text{Dependent}\\ \\ \text{Dependent}\\ \\ \\ \\ \end{array}$$

The second step is to list the same vector with the dependent coordinates first, then the independent coordinates. This must be done for each component. The resulting vector is called vector A.

$$\left[\begin{array}{c}3\\4\\1\\2\\5\\6\\9\\10\\7\\8\end{array}\right]\quad\begin{array}{l}\text{Dependent}\\ \\ \\ \\ \text{Dependent}\\ \\ \text{Dependent}\\ \\ \\ \\ \end{array}$$

The third step is to list vector A with all the dependent coordinates first then all the independant coordinates which yield vector B:

$$\begin{bmatrix} 3 \\ 4 \\ 9 \\ 10 \\ 5 \\ 6 \\ 1 \\ 2 \\ 7 \\ 8 \end{bmatrix} \qquad \text{Dependent Coordinates}$$

Vector A and vector B are placed side by side as follows:

$$\begin{array}{ccc} \begin{bmatrix} 3 \\ 4 \\ 1 \\ 2 \\ 5 \\ 6 \\ 9 \\ 10 \\ 7 \\ 8 \end{bmatrix} & \qquad\qquad & \begin{bmatrix} 3 \\ 4 \\ 9 \\ 10 \\ 5 \\ 6 \\ 1 \\ 2 \\ 7 \\ 8 \end{bmatrix} \\ \text{vector A} & & \text{vector B} \end{array}$$

The next step is to ask the computer to arrange the vector A coordinates as they appear in vector B. Vector A is stored in the computer's memory but it has to be supplied with a map to enable it to go from vector A to vector B. The vector IARANG is that map and is formed as follows. The position of the numbers in vector A is checked as they appear in vector B and that order is written down. For example, the number "3" in vector A appears first in vector B so it is written down as 1 in the first space of IARANG. The "4" appears second so a 2 is written down. The "1" appears seventh in vector B so it is written down as 7. The "2" appears eighth so it is written down as 8. The "5" appears so it is written down as five. And so on. Thus the vector IARANG looks like this:

$$\begin{bmatrix} 1 \\ 2 \\ 7 \\ 8 \\ 5 \\ 6 \\ 3 \\ 4 \\ 9 \\ 10 \end{bmatrix}$$

Next, card 46 is punched as follows:

Card 46: IARANG Card (Column 2):

<u>IARANG(1)=a,b,c,d,e,f,g, etc</u>.

or in the case of our example

IARANG(1)=1,2,7,8,5,6,3,4,9,10,

Card 47:

<u>$END</u>

Card 48: (column 2),

<u>$START NTYPE=4, $END</u>

This stops the program

Card 49: (starting in column 1):

6/7/8/9

5. HUNTING ANALYSIS - DYNALIST OUTPUT INTERPRETATION

The complex eigenvalue extraction capability of DYNALIST is a tool for the analysis of lateral dynamic stability of rail vehicles. In certain ranges of vehicle velocity, one or more modes of vibration of the vehicle may grow rather than decay with time. The eigenvalue analysis assumes modal response of the form $e^{\lambda t}$, where $\lambda = \sigma + i\omega t$ is a complex eigenvalue. A hunting mode is indicated if $\sigma > 0$, since the response $e^{\sigma t}\ e^{i\omega t}$ would increase in amplitude with time.

The velocity effects in a DYNALIST rail vehicle model are represented by the elements of the stiffness and damping matrixes which are functions of wheel rail interaction. Therefore, to perform a hunting analysis, several DYNALIST runs must be made with matrix element of a given run corresponding to one of the velocities in the range of interest.

Table 9 shows a list of the real and imaginary parts of the eigenvalues for a run of the 14 DOF model discussed in Section 3. (Note that this list is output by DYNALIST only for an assembled model, not for a component). These eigenvlaues are conjugate pairs. Each pair corresponds to one vibration mode or eigenvector.

DYNALIST outputs the eigenvector for each eigenvalue as a list of real and imaginary components corresponding to the coordinates of the model. A sample of this output in Table 9 for the assembled vehicle model has 18 components. The "extra" four are the coupling coordinates defined for the truck component. Note that the values for the eighth, tenth, and eighteenth coordinates are identical as required by the constraint equations for the yaw of the body and the coupling coordinates.

The normalization of each eigenvector on its largest component permits an identification of the physical mode corresponding to each eigenvalue. In this example, the 1.0 value is the lateral displacement of one of the rear truck wheelsets, coordinate 11 in the assembled model.

TABLE 9. SAMPLE OF DYNALIST OUTPUT

```
EIGENVALUES

 -5.257933E+01   -6.870713E+01
 -5.257933E+01    6.870713E+01
 -5.257744E+01   -6.867808E+01
 -5.257744E+01    6.867808E+01
 -2.549450E+01    7.881063E+01
 -2.549450E+01   -7.881063E+01
 -2.545806E+01    7.879966E+01
 -2.545806E+01   -7.879966E+01
 -5.443178E+00    2.237710E+01
 -5.443178E+00   -2.237710E+01
 -5.507921E+00    2.227486E+01
 -5.507921E+00   -2.227486E+01
 -1.331225E+00    5.964313E+00
 -1.331225E+00   -5.964313E+00
 -8.636231E-01   -4.418601E+00
 -8.636231E-01    4.418601E+00

TRANSFORMED EIGENVECTOR FOR ROOT -5.2579332E+01 -6.8707127E+01

      REAL           IMAGINARY
 7.3566261E-01 -2.9197367E-01
-4.9803539E-02 -9.5760037E-03
-5.3920186E-03 -3.8799222E-01
-3.5833623E-02 -4.7160672E-03
 5.7820631E-01 -7.1307007E-02
-4.7715270E-02 -1.1757323E-02
 6.0178545E-03  5.3254109E-03
 2.5036490E-05 -3.8858522E-05
 4.9788402E-03  6.9380396E-03
 2.5036490E-05 -3.8858522E-05
 1.0000000E+00  0.
-5.4026987E-02 -3.4459756E-02
 1.7455838E-01 -4.5812181E-01
-3.9885821E-02 -2.2240787E-02
 7.1222264E-01  1.8576198E-01
-5.0557711E-02 -3.6048168E-02
 3.9398259E-03  8.5506682E-03
 2.5036490E-05 -3.8858522E-05
```

A convenient form for presentation of hunting analysis results is shown in Figure 8. At a given velocity each conjugate pair of eigenvalues is plotted. The imaginary part is the frequency and is displayed as the DYNALIST output (which is in radians/sec) divided by 2π, i.e. Hz. The real part can be interpreted as damping ratio by dividing it by the magnitude of the imaginary part (actually $\zeta = \frac{\sigma}{\omega_o}$, but $\omega_o \approx \omega$ for small ζ). As the velocity increases, some of the modal damping ratios may become less negative. When a damping ratio becomes positive (usually a wheelset mode), it defines a critical velocity for that mode. Such a velocity can be interpreted as a boundary of linear stability.

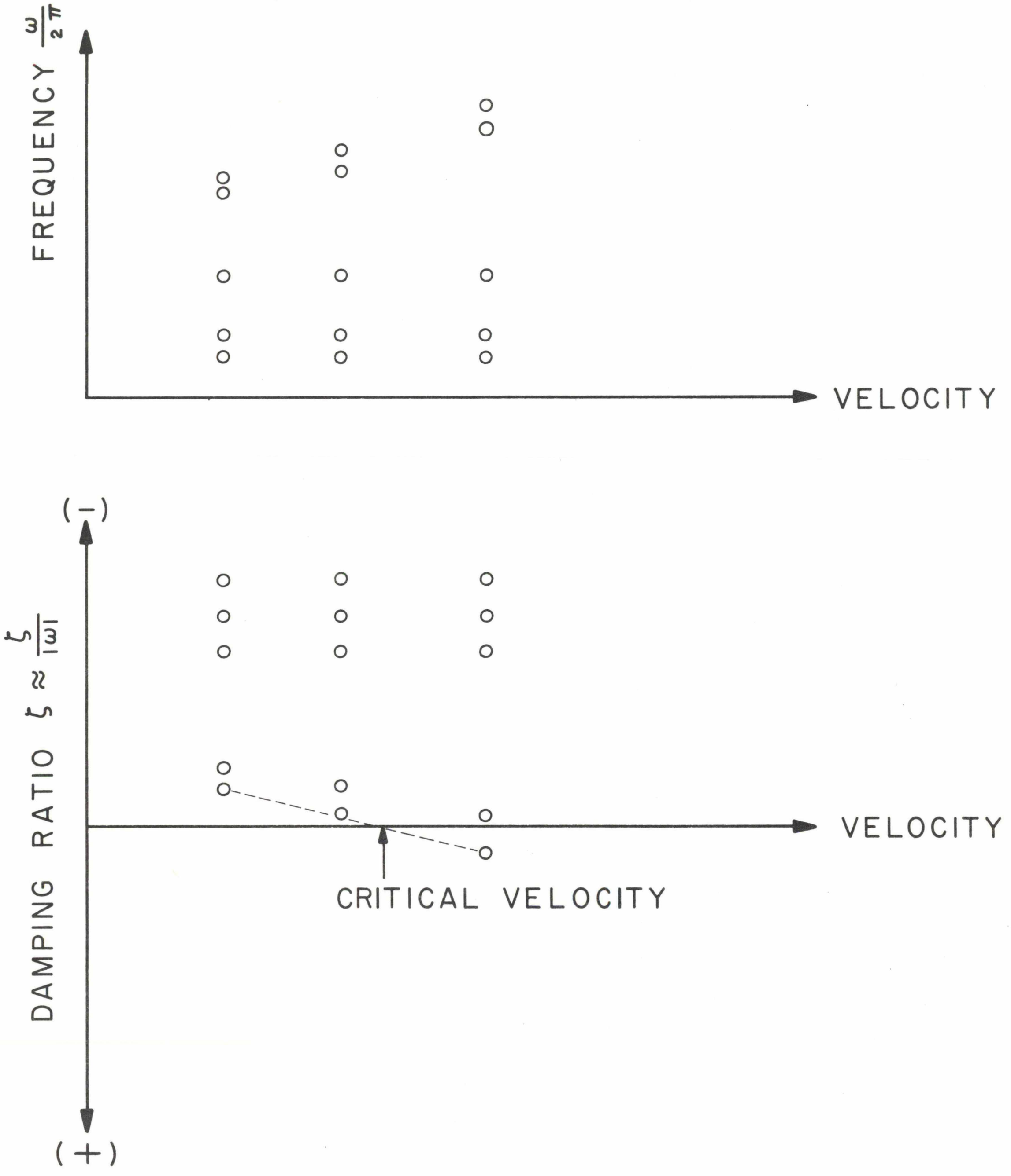

Figure 8. Hunting Plot

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